

Stress analysis on the free-end distal extension of an implant-supported mandibular complete denture

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Abstract: A comparative and qualitative analysis of the tensions generated in the cantilever region of an implant-supported mandibular complete denture was conducted using the three-dimensional finite element method. The mechanical properties of the components were input in the model and a load of 15 N was applied in pre-determined points. In the first simulation, the load was applied on the occlusal surface of the first premolar. In the second simulation, it was applied on the first and second premolars. In the third simulation, it was applied on the first and second premolars and on the first molar. The different occlusion patterns produced similar tension distributions in the cantilever region, which followed a similar pattern in the three simulations. In all of the cases, the highest levels of tension were located in the region of the first implant. However, as the loads were dislocated distally, the tensions increased considerably. The more extensive the cantilever, the more compromised will be the infrastructure, the prosthetic components and the implants. Regardless of the length of the cantilever, the highest tensions will always be located in the region of the implant next to the load application point.

Descriptors: Dental occlusion; Dental implantation; Biomechanics.

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Introduction

There is a great controversy in the related literature about which occlusion pattern should be established in dental rehabilitations using cantilever implant-supported prostheses.¹⁻³ Since the beginning of osseointegration, when the Brånemark protocol composed of a fixed prosthesis with five or six implantations as pillars in the mental region and bilateral cantilevers was proposed, there has been an interest not only in determining the most suitable occlusal configuration, providing a harmonious and effective disclusion, but also in understanding the relationships of this configuration with the stomatognathic system.⁴ Thus, the relationship between the involved occlusal factors and chewing muscles, masticatory efficiency, bruxism, temporomandibular articulation, adjacent tissues, etc. has been investigated. Few consistent and scientifically sound conclusions, however, have been reached. In the natural dentition, the canine guide is the most frequent disclusion pattern during contacting border movements.⁵ The occlusion pattern may be considered a critical factor for the longevity of osseointegrated implants. In the natural dentition, the presence of periodontal ligament leads the teeth to behave very differently from how osseointegrated implants do. The tensions transmitted to the components of the implants and to the bone/implant interface are thus totally different from those observed in the natural dentition. If the occlusal forces exceed the absorption ability of the system, the implant will fail due to the overloads and to the poor distribution of the masticatory forces, amongst other factors.^{3,6} The literature pertinent to this subject is still scarce in qualitative and quantitative evaluations of the effects of the tensions generated on the prosthesis, prosthetic components, implants and supporting bone structure. The modeling of these tensions with computer graphics programs and the biomechanical analysis rendered by the three-dimensional finite element method (3D-FEM) are promising alternatives for addressing the subject. In addition, they have the advantage of not being invasive and of allowing the study of regions that would otherwise be very difficult to gain access to. That is the case, for example, of the studies aimed at measuring the tensions, com-

pressions and displacements related to implants and respective supporting structures.

Thus, taking advantage of the availability of these technologies, the present study analyzed the biomechanical behavior of the implants and prosthetic components supporting an implant-supported mandibular complete denture using the three-dimensional finite element method (3D-FEM). The study's purpose was to contribute to the understanding of the consequences of the tensions generated to the implants and supporting structures simulating the physiological occlusal conditions observed in the free-end distal extension of this kind of prosthesis.

Material and Methods

Using the program SolidWorks® Office Premium 2006 (SolidWorks Corporation, Concord, MA, USA), three-dimensional models were drawn simulating an implant-supported mandibular complete denture with the features of a prosthesis produced following the Brånemark protocol. Hence, five implants (Titamax II, Neodent®, Curitiba, PR, Brazil) were simulated as pillars, located in the interforamen region of the mentum, upon which a complete denture was simulated with a metallic infrastructure in nickel-chromium (Wironia® BEGO, Bremer/Germany), with twelve artificial teeth (Ivoclar Vivadent Ltda., São Paulo, SP, Brazil), i.e., from mandibular left first molar to mandibular right first molar. A small gingival band in heat-cured acrylic resin (Classico/RMV, São Paulo, SP, Brazil) was simulated, without contact with mucosal tissue, observing an area of 3 mm for hygienization.

The five titanium implants were distributed observing a distance of 4 mm between their platforms. All the implants were simulated as being cylindrical, with 13 mm in height and 3.75 mm in diameter, with external hexagon and a platform of 4.1 mm.

The prosthetic components, also made of titanium (Mini Pilar Cônico, Neodent®, Curitiba, PR, Brazil), were simulated with 3 mm in height and platform of 4.1 mm, and they were installed with a torque of 20 N to guarantee an accurate fit (Figure 1).

The metallic infrastructure in nickel-chromium was simulated with a thickness of 6 mm, height of 4 mm and a total length of 58.75 mm. These mea-

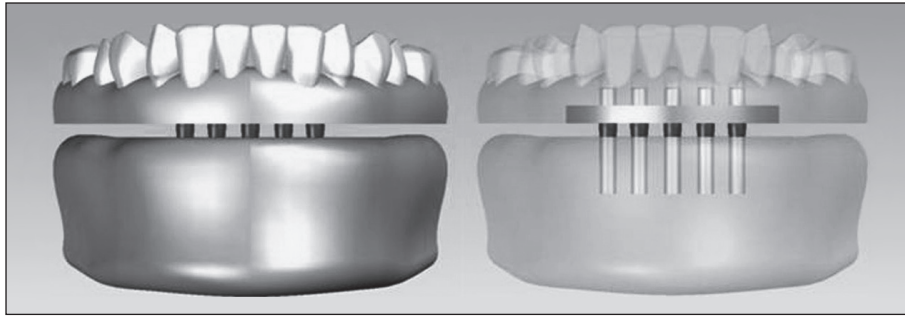


Figure 1 - Finite element model of an implant-supported mandibular complete denture.

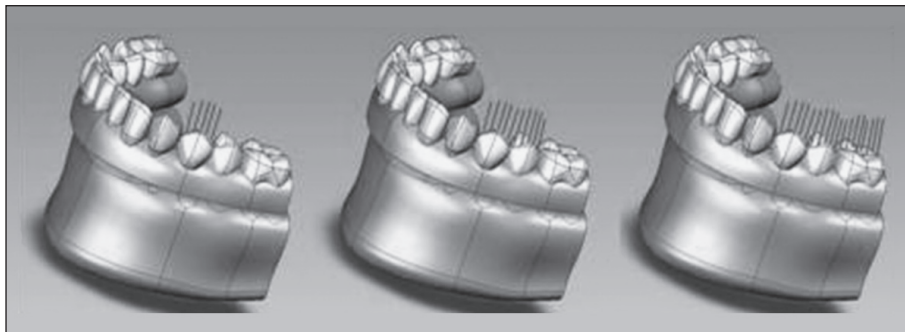


Figure 2 - Locations of the occlusal load application points, in the three simulations of the study.

surements provided a distal extension of 12 mm on each one of the prosthesis extremities.

A gingival portion in heat-cured acrylic resin and 12 artificial teeth were simulated over this infra-structure.

The coefficient of Poisson (ν) and the Modulus of elasticity (E) of each one of the elements composing the models were simulated following the values established in the pertinent literature. Hence, the following parameters were defined:

- Spongy alveolar bone - 1,370 MPa (E) and 0.30 (ν);
- cortical alveolar bone - 13,700 MPa (E) and 0.30 (ν);
- nickel-chromium alloy - 188,000 MPa (E) and 0.28 (ν);
- titanium - 110,000 MPa (E) and 0.35 (ν);
- acrylic resin - 2,700 MPa (E) and 0.35 (ν).

A load of 15 N was applied, distributed on the occlusal surface of different teeth according to three simulations:

- In the first simulation, the load was applied on the first premolar;
- in the second simulation, the load was distributed on first and second premolars;

- in the third simulation, the load was distributed on the first and second premolars and on the first molar.

The applied force was divided among the application points located right after the end of the metallic infra-structure, i.e., at a distance of 13 mm from the first implant, as shown in Figure 2.

A total of thirty data collection points were uniformly distributed extending over the nickel-chromium infra-structure, starting from the initial point of the cantilever on the working side (point 01) and extending to the end point of the cantilever on the balancing side (point 30).

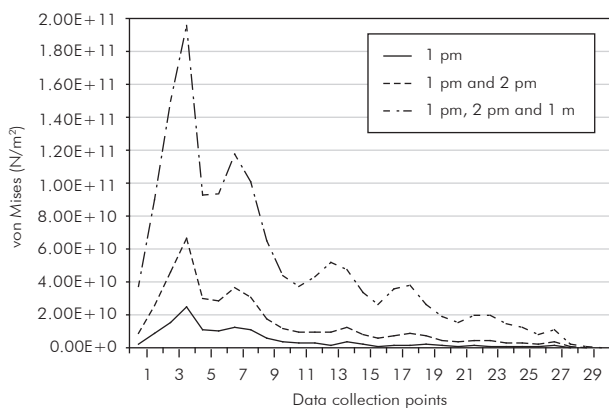
For each of the simulations studied, the values obtained for the displacement magnitude (vectorial average of the displacements in the main axes x , y and z) were recorded in the form of graphs and compared.

Results

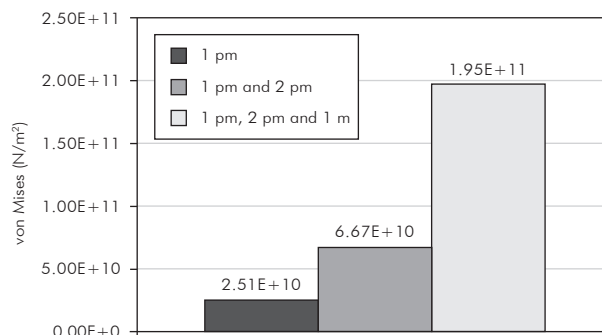
The results from the analysis of the distribution of the tensions on the nickel-chromium infra-structure, on the prosthetic components and on the implants are presented in Figures 3 through 8.

The distribution of the occlusal loads in the three

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Graph 1 - Analysis of the tensions generated by the occlusion loads applied in the three simulations of the study (pm: premolar; m: molar).



Graph 2 - Maximum tension values in the three simulations of the study (pm: premolar; m: molar).

Figure 3 - Occlusal load applied on the first premolar.

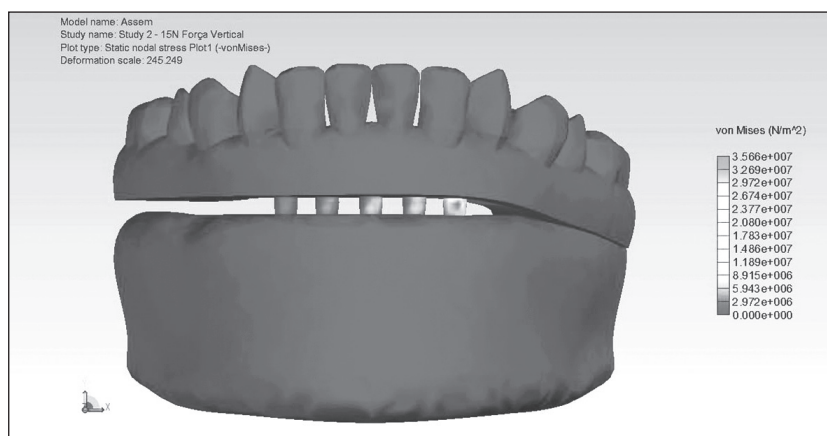
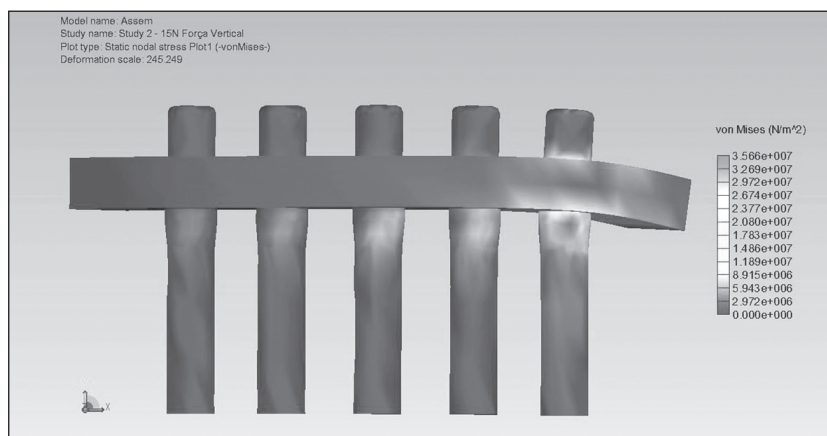


Figure 4 - Occlusal load applied on the first premolar. Anterior view and working side.



simulations generated stress information on the data collection points distributed over the extension of the metallic nickel-chromium infrastructure, as shown in Graph 1.

Analyzing the graph of the tensions generated on the metallic nickel-chromium infrastructure, on the prosthetic components and on the implants, it can be observed that the greatest tensions are located next

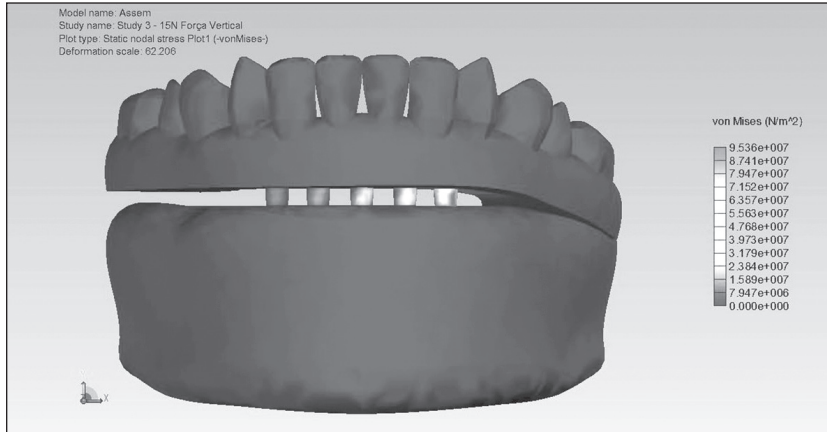


Figure 5 - Occlusal load applied on the first and second premolars.

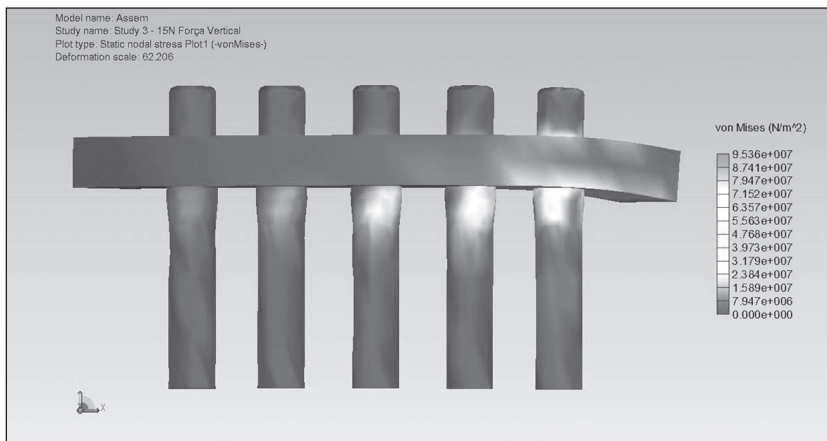


Figure 6 - Occlusal load applied on the first and second premolars. Anterior view and working side.

to the loading points, on the metallic infrastructure and around the first implant. From the second implant on, towards the free-end of the balancing side, the tensions gradually decrease in all the three simulations.

It can also be observed that the profiles of the curves generated in the three simulations follow a same pattern, indicating that the load application on the cantilever generates tensions on the same points of the infrastructure, even while varying the position of these applications.

On the other hand, when the load is applied more distally (on the first and second premolars in the second simulation; on the first and second premolars and on the first molar in the third simulation), even though the total load remains the same (15 N), the stress endured by the infrastructure is considerably bigger in the second and third simulations, as shown in Graph 2.

Discussion

Several renowned authors^{1,5,7-12} have stated that to decrease the lever arm, the length of the cantilever in mandible should not exceed 20 mm. Others argue that the length of the cantilever should not exceed two times the width of a premolar.¹³ Yet others say that the length of the cantilever should not exceed the anteroposterior length of the area where the implants are distributed, and that an implant distribution with an anteroposterior length greater than 11.1 mm will produce a cantilever length which is adequate to promote satisfactory biomechanics, in addition to producing a favorable esthetic and phonetic result.^{14,15}

The greater the length of the cantilever, the greater will be the tensions generated on the implants next to it. The load application (vertical, horizontal, or latero-horizontal) on the cantilever will produce a compression tension on the more distally positioned

Figure 7 - Occlusal load applied on the first and second premolars and on the first molar.

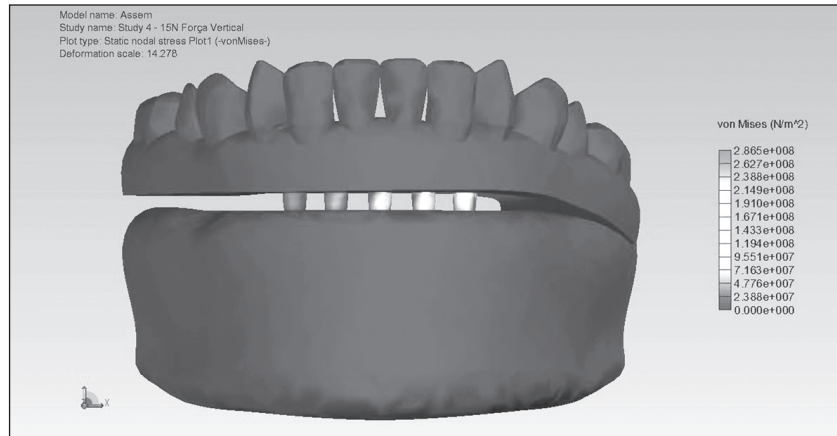
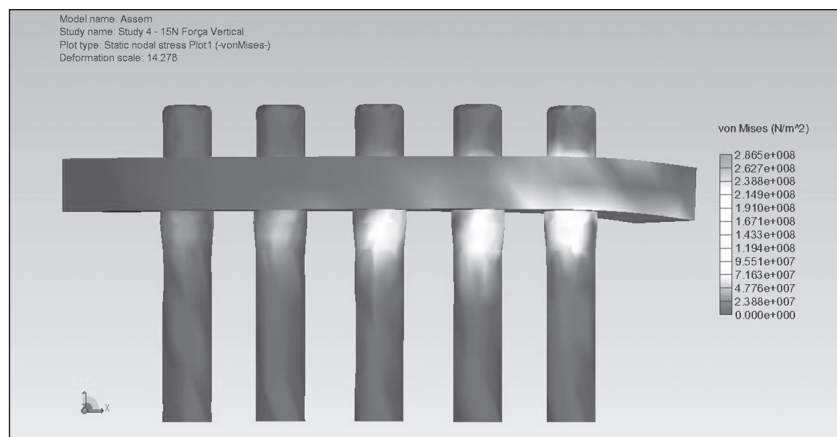


Figure 8 - Occlusal load applied on the first and second premolars and on the first molar. Anterior view and working side.



implant, and a pull tension on more proximally positioned implants.^{5,13-18}

The tensions on the implants closer to the load application point are 1.75 to 3.5 times greater than those produced by application of a same load on a system without a cantilever.¹⁰ Based on these reports, it is recommended that the arches of a free-end prosthesis be joined by a metallic infrastructure so that the implants on one side may help balance the tensions generated on the other.

In a study retrieved from the related literature, a prosthesis with two teeth in cantilever was evaluated, and the forces of closing and chewing were assessed. First, the first tooth of the cantilever was placed in occlusion and the second tooth, in infra-occlusion; then, the opposite situation was created and analyzed. Based on the results of the study, the authors recommend that the second tooth should always be placed in infra-occlusion.¹⁹

A judicious evaluation of the implant to be placed next to the cantilever should always be made before determining the length of the cantilever.¹⁶ If the terminal implant does not have enough support and/or lacks proper size, the arm of the cantilever will have to be drastically reduced or its use should even be altogether avoided.

The distribution of the vertical and lateral loads applied to an implant-supported prosthesis depends on the number, arrangement and resistance of the implants used, as well as on the form and resistance of the prosthetic restoration itself. Prostheses with cantilevers have to endure an increased load on the implants next to their distal extensions.²⁰ The application of loads on the infrastructure of an implant-supported prosthesis produces a certain amount of deformation energy on the system. As a result, deformation and deflection of the infrastructure are to be expected. If a great amount of deformation en-

ergy is consumed close to the load application point (assuming that a high concentration of stress occurs around the closest implant), a great reduction in the energy transmitted to the remaining implants and low concentration of stress occurs on them.¹⁷

This stress distribution was observed in the present study during application of the occlusal loads in all the simulations.

Hence, the results of the present study were those expected, i.e., the greater the length of the cantilever, the greater will be the tensions endured by the infrastructure, and the distributions of these tensions are situated in the same regions, even if the

values of the tensions generated are much higher.

Conclusion

Based on the results of the present study, the following conclusions were drawn:

- The greater the extent of the cantilever, the more compromised will be the metallic infrastructure in nickel-chromium, the prosthetic components and the implants.
- Regardless of the length of the cantilever, the greatest tensions will always be located on the region of the implant closest to the load application point.

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